

FRACTURING DIFFERENT LEVELS
WITHIN A COMPLETION INTERVAL OF A WELL

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DESCRIPTION

1. Technical Field

The present invention relates to completing a subterranean formation and in one of its aspects relates to a method and apparatus for fracturing different levels of a completion 10 interval of a subterranean formation(s) in a single operation.

2. Background Art

In completing wells used in the production of hydrocarbons or the like, it is common to "hydraulically fracture" at least some interval of the production/injection formation(s) in order 15 to improve flow of fluids into and/or out of the formation. As is well understood in the art, hydraulically fracturing is typically carried out by lowering a workstring into the well and isolating that portion of the wellbore which lies adjacent the interval to be fractured by setting packers or the like. 20 Fracturing fluid or slurry (e.g. a heavy gel with or without props) is then pumped down the workstring and into the isolated interval at a pressure sufficient to separate or "fracture" the formation, thereby forming permeable channels within the formation.

25 In thin or relatively short intervals that are fairly homogeneous, standard fracturing techniques such as described above will normally produce a fracture or fractures throughout the length of the completion interval. However, these standard fracturing techniques experience problems when used in 30 fracturing long or thick intervals or in intervals which are heterogeneous (i.e. made of several levels or zones which fracture under different pressures). For example, it is difficult, if possible at all, to fracture a second zone in such intervals once a first zone has started to fracture. The 35 fracturing slurry will continue to flow into and enlarge the initial fracture as the pressure increases in the isolated

portion of the wellbore rather than initiate additional fractures in the other zones or levels of the fracture interval.

Further, liquid from the fracturing slurry is typically "lost" into the formation through the initial fracture causing props, e.g. sand, to settle out of the slurry thereby forming a bridge or blockage within the wellbore adjacent the initial fracture. Such blockages prevent further flow of slurry to other zones in the fracture interval even if such zones had already experienced some initial breakdown, i.e. fracturing. This results in poor distribution of fractures throughout the fracture interval since often only the zone having the lowest breakdown pressure will be adequately fractured and propped.

Due to these problems, it is common to fracture a long and/or heterogeneous interval by carrying out a series of individual, conventional fracturing operations such as described above. That is, a first zone is fractured, then the workstring is repositioned in the wellbore and a second zone is fractured, and so on until the entire interval has been fractured. Of course, as will be recognized by those skilled in this art, this repetition is both expensive and time consuming and can significantly affect the overall economics of the well being completed.

To overcome the problems in fracturing long and/or heterogeneous intervals, several methods have been proposed wherein the fracturing of such intervals can be carried out with a single setting of a workstring wherein the fracturing slurry is delivered simultaneously to the different levels or zones within the interval through alternate flowpaths; for example, U.S. Patent 5,161,618 to Jones et al. Another such method is disclosed in U.S. Patent 5,435,391, issued July 25, 1995, wherein alternating slugs of a gel and a proppant slurry are pumped down a single workstring and through alternate flowpaths to fracture and prop different levels within the fracture interval. .

Still another such method is that disclosed in U.S. Patent 5,417,284, issued May 23, 1995, wherein a fracturing gel is pumped down a workstring and into one end of the isolated wellbore while a proppant slurry is pumped at the same time

through the well annulus and into the other end of the isolated annulus to carry out the fracturing of the different levels within the isolated interval. If a blockage occurs, the fracturing gel and/or slurry continues to be delivered 5 throughout the fracture interval through alternate flowpaths to complete the fracturing of the interval.

A similar method is disclosed in U.S. Patent 5,560,427 except a slurry splitter is positioned downhole in the workstring wherein a portion of the gel is separated from the 10 fracturing slurry and is flowed into the bottom of the isolated interval to initiate fracturing within the interval. The remainder of the slurry is flowed into the upper end of the isolated interval to prop the fractures as they are being formed. Alternate flowpaths are provided to insure that the gel 15 and/or slurry will be delivered to the different levels within the interval should a blockage occur in the well annulus before the fracturing operation is complete.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for 20 fracturing different levels of a completion interval of a subterranean formation which is traversed by a wellbore of a well. Basically, a workstring comprised of a tubing having a cross-over and a fracturing string is lowered into the wellbore until the fracturing string is positioned adjacent the completion interval to be fractured. The fracturing string is 25 comprised of a base pipe which is essentially blank over most of its length (i.e. impermeable) except for a plurality of perforated sections which are spaced along its length. Each perforated section is formed by a plurality of openings (e.g. round holes, slots, etc.) through the wall of the base pipe which are spaced around and throughout the length of the 30 perforated section. The lengths of the respective perforated sections may vary (e.g. from about 1 to about 300 feet) with the perforated sections being spaced from each other along the base pipe at varying distances (e.g. from about 10 to about 1000 35 feet).

In fracturing formations where little or no substantial particulate material, e.g. sand, will be produced with the

formation fluids, the openings in the perforated sections may be merely un-screened openings through the base pipe, similar to the slots in a conventional "slotted liner". In formations where substantial sand will be produced, a screen means, e.g. 5 wire wrap, is positioned over the openings at each perforated section to allow fluid to flow into the base pipe through the openings while preventing any substantial sand from flowing therethrough. At least one alternate flow path (e.g. shunt tubes) having an inlet and one or more spaced outlets, is 10 provided on the fracturing string and extends longitudinally along the length of the base pipe. The wire wrap can be wrapped over the shunt tubes at each perforated section or the shunt tubes can be bent to pass over the wire wrap after the wire is 15 in place on the base pipe. Where the shunt tubes are outside the wire wrap, a perforated sleeve or shroud can be positioned over the shunts at each perforated section to protect the shunts tubes during installation.

To carry out the fracturing method of the present invention, the workstring is positioned within the wellbore so 20 that the fracturing string will extend substantially through said completion interval and will form a "completion interval annulus" with the wellbore which, in turn, is isolated from the well annulus above. A fracturing slurry, comprised of a 25 fracturing liquid (e.g. high-viscosity gel) and proppants (e.g. sand), is flowed down the tubing string and out through the cross-over into the top of the completion interval annulus. As is common in routine fracture operations, a pad of fracturing fluid without proppant can be pumped into the completion interval annulus before the slurry to initiate the fracturing of 30 the formation, if desired.

As will be understood in the art, when returns are taken through the well annulus, liquid from the fracturing slurry is lost both into the formation(s) within said completion interval and into said base pipe through the openings in the perforated 35 sections along the base pipe. This causes the proppants (sand) from the slurry to "sand-out" within the completion interval annulus at the perforated sections to form sand bridges which,

in turn, block further flow of slurry down through the completion interval annulus.

These sand bridges or blockages effectively act as packers which isolate portions of the completion annulus which lie between respective adjacent, perforated sections. The pumping of the slurry into the top of the completion interval annulus is continued but now it can only flow downward therein through the alternate flowpaths, i.e. shunts tubes. The slurry enters the tops of the tubes and flows downward to exit through the spaced outlets at different levels within the completion interval annulus; that is, the slurry exits into the isolated portions of the completion interval annulus. Continued pumping of the slurry will cause the pressure to build up within these isolated sections until the different levels within the completion interval are fractured and propped with the proppant. If any level of the completion interval is not to be fractured, no outlets are provided in the shunt tubes at this level; accordingly, no fracturing slurry can exit into the isolated portion of the completion interval annulus which lies adjacent to the level which is not to be fractured.

Where returns are not to be taken through the well annulus, the flow of fluid into or through the base pipe is blocked since the base pipe and well annulus are filled with a non-compressible, completion fluid. Therefore, no substantial amount of liquid from the fracturing slurry will be initially lost through any of the perforated sections but will only be lost into the formation. Eventually, the formation will fracture at some level within the completion interval. Once this initial fracture is formed, liquid can now flow not only into the fracture but also into the base pipe through some of the perforated sections and back out into the completion interval annulus through the perforated section nearest the initial fracture.

This causes sand bridges to form at the perforated sections where liquid is being lost from the slurry. These sand bridges form "packers" which, in turn, isolate the portions of the completion interval annulus which lie therebetween. Slurry now can only flow through the alternate flow paths which deliver

the slurry into the isolated portions of the completion interval annulus to finish the fracturing operation.

Once the completion interval has been fractured and propped, flow of slurry is ceased and the well is put on production. The fluids from the completion interval flow into the completion interval annulus and due to the difference in the viscosity of the slurry liquid (e.g. about 100 centipoises) and the produced fluids (e.g. about 1 centipoise), the produced fluids can readily flow through the sand bridges and into the base pipe through the openings in the perforated sections of the base pipe. Where a substantial amount of sand is produced with the formation fluids, the openings in the perforated section will be equipped with a screen means (e.g. wire wrap) which allows the produced fluids to pass therethrough while blocking any substantial flow of particulates.

BRIEF DESCRIPTION OF THE DRAWINGS

The actual construction, operation, and the apparent advantages of the present invention will be better understood by referring to the drawings, not necessarily to scale, in which like numerals identify like parts and in which:

FIG. 1 is an elevational view, partly in section, of a portion of a wellbore having a fracturing string of the present invention in an operable position adjacent a completion interval to be fractured;

FIG. 2 is an enlarged, elevational view, partly in section, of a portion of the fracturing string of FIG. 1;

FIG. 3 is a sectional view taken through the line 3-3 of FIG. 2;

FIG. 4 is an elevational view, partly in section, of a further embodiment of the fracturing string of the present invention;

FIG. 5 is a partial elevational view of still another embodiment of the fracturing string of the present invention; and

FIG. 6 is an elevational view, partly in section, of a portion of a wellbore having another embodiment of a fracturing string of the present invention in an operable position adjacent a completion interval to be fractured.

While the invention will be described in connection with its preferred embodiments, it will be understood that this invention is not limited thereto. On the contrary, the invention is intended to cover all alternatives, modifications, 5 and equivalents which may be included within the spirit and scope of the invention, as defined by the appended claims.

BEST KNOWN MODE FOR CARRYING OUT THE INVENTION

Referring more particularly to the drawings, FIG. 1 illustrates a portion of the wellbore 11 of a producing and/or injection well 10. Wellbore 11 extends from the surface (not shown) through a long completion interval 12 (i.e. production/injection interval). Well 10 is illustrated as having a vertical, "open hole" wellbore but it should be recognized by those skilled in the art that the present invention is equally applicable for use (a) in cased wells which are perforated adjacent the zones to be fractured as well as (b) in inclined and/or horizontal wellbores. Since the present invention is applicable for use in horizontal and inclined wellbores as well as vertical wellbores, the terms "upper and lower", "top and bottom", as used herein are relative terms and are intended to apply to the respective positions within a particular wellbore while the term "levels" or "zones" is meant to refer to respective positions lying along the wellbore between the terminals of the completion interval 12.

As illustrated, completion interval 12 is a formation(s) having a substantial length or thickness which extends along wellbore 11 and which is made up of a plurality (three shown) different levels or zones 13A, 13B, and 13C which, in turn, may be heterogeneous (i.e. each zone breaks down under a different fracturing pressures). A workstring 14 is positioned in wellbore 11 and extends from the surface (not shown) and substantially through completion interval 12. As illustrated, workstring 14 includes a fracturing string 15 which is connected through a conventional "crossover" 16 onto the lower end of tubing string 17 and which is positioned adjacent the completion interval 12 when in its operable position.

Fracturing string 15 is comprised of length of base pipe or conduit 20 which extends substantially throughout the

completion interval 12 to be fractured. Base pipe 20 is blank (unperforated) throughout most of its length except for a plurality of spaced, perforated sections 21a, 21b, 21c, 21d which, in turn, are formed by a plurality of openings (e.g. 5 holes 22a at 21a, slots 22b in 21b, FIG. 2) radially spaced around the base pipe and extending in rows throughout respective lengths "L" of base pipe 20. Openings 21 may be provided directly through base pipe 20 or each perforated section or may be formed in a separate coupling or length of pipe which is then 10 joined into base pipe 20 at the appropriate spaced intervals. Openings 21 allow fluids to flow into base pipe 20 from the surrounding completion interval annulus 30a (FIG. 1), for a purpose described below. Both the length "L" of each perforated section 20a-d (e.g. between about 1' to about 300 feet) and the 15 longitudinal spacing between perforated sections 21 (e.g. from about 10 to about 1000 feet, preferably about 10 feet apart) may vary within a single base pipe 20 depending on the characteristics of the particular interval 12 to be fractured.

One or more (e.g., four shown in FIG. 3) relatively small 20 shunt tubes 24 (i.e., 1 to 1-1/2 inch diameter or smaller) are spaced radially around and extend longitudinally along the length of fracturing string 15. These shunt tubes may be round in cross-section (e.g. 24a, FIG. 3) or take other cross-sectional shapes (e.g. substantially rectangular, 24b, FIG. 3). 25 Each of shunt tubes 24 has one or more outlets (e.g. spaced openings 25) along its respective length which provide "alternate flowpaths" for the delivery of fluids to different levels within the completion interval 12 as will be further discussed in detail below.

30 Each shunt tube may be open at least at its upper end to allow fluids to enter therein or where a plurality of outlets 25 are present, the entry of fluid may be provided through some of the openings 25, themselves (e.g. , those near the top of each the tube). Further, while outlet openings 25 in each shunt tube 35 24 may open through the front of the tube, they may also exit through each side of shunt tube. Shunt tubes of this type have been used to provide alternate flowpaths for fluids in a variety

of different well operations, see US Patents 4,945,991; 5,082,052; 5,113,935; 5,161,613; and 5,161,618.

While the openings 22 in each perforated section 21 are designed to allow flow of fluid into base pipe 20, it is important that the flow of particulate material (e.g. proppants, produced sand, etc.) be blocked. This is not a problem when no substantial amount of particulate material will be produced along with the formation fluids from the fractured formation. Accordingly, unscreened openings (e.g. slots 22c, FIG. 5) may be provided in base pipe 20 in the same manner as the small slots are provided in well known, commercially-available "slotted liners". However, where substantial amounts of particulate material will be produced along with the formation fluids, a screening means is provided over the length "L" of each perforated section 21 and is sized to allow the flow of fluids therethrough while blocking any substantial flow of particulates, this being well understood in the well screen art.

The screening means may be comprised of any well known material which screens out the particulate material while allowing fluids to pass therethrough. For example, as illustrated in FIGS. 1-4, the screening means is comprised of a continuous length of a wrap wire 31 which, in turn, may be cut in a "keystone" cross-section (not shown). Wire 31 is wrapped around base pipe 20 to cover the openings 22 throughout a respective perforated section 21 and can be welded or otherwise secured thereto. Each coil of wire is slightly spaced from its adjacent coils to thereby form fluid passageways (not shown) between the respective coils. This is basically the same technique as is commonly used in the manufacture of many commercially-available, wire-wrap screens used in well completions. In one embodiment of the present invention (FIGS. 1-3), wire 31 is first wrapped around base pipe 20 at each perforated section 21 before shunt tubes are positioned and secured onto the base pipe. Each shunt tube is then slightly bent at each perforated section 21 to conform with the outer surface of the wire-wrap 31 as it transverses same.

Further, in this embodiment, a perforated sleeve or shroud 33 (only one shown at 21b in FIG. 2) may be placed over an

entire perforated section 21 to protect shunt tube 24 during installation into wellbore 11 and to act as a centralizer for fracturing string 15, if needed. Shroud 33 can be made in two pieces and then welded or otherwise secured together after the 5 pieces are fitted around section 21.

In another embodiment (FIG. 4), shunt tubes 24a are first positioned across perforated sections 21 and then wire 31 is wound over both base pipe 20 and shunts 24a. In this embodiment, the wire 31 protects the shunt tubes at each 10 perforated section 21. It should be understood that the gap (i.e. well annulus 30, FIG. 1) between the wellbore 11 and the fracturing string 15, especially at the wire-wrapped, perforated sections 21, will be small (i.e. 1 to 1½ inches) in most well completions.

15 In operation, if wellbore 11 extends for a distance substantially below the bottom of completion interval 12, the wellbore is blocked-off adjacent the lower end of fracture interval 12 by a plug or packer (not shown), as will be understood in the art. Where fracture interval 12 will produce 20 substantial amounts of particulate material along with the formation fluids when well 10 is put on production, the workstring 14 of FIG. 1, having cross-over 16 and fracturing string 15 at its lower end, is lowered into wellbore 11 thereby forming a well annulus 30 between the workstring 14 and the wellbore 11. Fracturing string 15 is positioned adjacent 25 completion interval 12 and packer 34, which is carried on the workstring, is set to isolate the completion interval annulus 30a which lies adjacent completion interval 12 from the rest of the well annulus 30. As will be understood in the art, wellbore 30 11 and workstring 14 will be filled with the completion fluid that is usually present in wellbore 11 as workstring 14 is lowered therein.

With workstring 14 in place, a fracturing slurry (arrows 35 40, FIGS. 1 and 2) is pumped down workstring 14, i.e. down through tubing 17, out ports 18 of cross-over 16, and into the top of completion interval annulus 30a. The fracturing slurry may be made up of any well-known carrier fluids commonly used for fracturing formations (e.g., water, etc.) and proppants

(e.g. sand) but preferably, the carrier fluid used in the fracturing slurry 40 of the present invention is a relatively, high-viscosity commercially-available "gel" (e.g. 100+ centipoises) of the type routinely used in conventional fracturing operations (e.g., Versagel, product of Halliburton Company, Duncan, OK. Of course, as is well known in the fracturing art, a pad of fracturing liquid (e.g. gel with no props) can be flowed into the wellbore before the slurry to initiate the fracture(s) if desired.

As the fracturing slurry 40 flows into the top of and down through completion interval annulus 30a, it begins to lose liquid into both the completion interval (e.g. zone 13A) and into base pipe 20 at the perforated sections 21. The liquid from the slurry will flow through the passageways formed between the coils of wire 31, through openings 22, into base pipe, through return pipe 16a in cross-over 16, and into well annulus 30 above packer 34. To insure rapid loss of fluid through each of the perforated sections 21, well annulus 30 above the cross-over 16 is opened at the surface to take returns from base pipe 20 through well annulus 30.

As liquid is lost from the slurry, "sand-outs", i.e. sand bridges or blockages 45, will form sequentially at each of the perforated sections. These blockages will form rapidly due to the leak-off of liquid from the slurry into both the zones of the completion interval and the base pipe 20. These bridges form effective barriers which prevent flow pass those points in the completion interval annulus 30a. That is, due to the high viscosity of the gel (e.g. 100+ centipoises), the liquid from the slurry can not readily flow through the sand bridges 45 once the bridges have formed. Only slight amounts of liquid from the slurry, if any, will pass through a respective sand bridge thereby slowly expanding the size of the sand bridge.

Since there are no openings in the blank, base pipe 20 except at perforated sections 21 and since the liquid from the slurry can no longer flow along annulus 30a once a sand bridge 45 is formed at a respective perforated section, slurry 40 now can only flow through the shunt tubes 24. The slurry enters the tops of tubes 24 and flows downward therein to exit into the

different levels in completion interval annulus 30a. In the embodiment shown in FIGS. 1-4-4, the slurry exits through the plurality of vertically-spaced, outlet openings 25 in the shunt tubes 24 which lie between adjacent perforated sections 21. In 5 the embodiment shown in FIG. 6, each shunt tube 24a is of a different length and has a single outlet at the bottom thereof through which the slurry exits at different levels within completion interval 12.

The sand bridges 45 effectively act as packers which, in 10 turn, which isolate the respective portions of completion interval annulus 30a which lie therebetween. Continued pumping of slurry through the shunt tubes 24 and out into the respective levels of the completion interval annulus 30a will increase the pressure of the slurry within the respective isolated portions 15 of the annulus 30a until a fracture is initiated in the respective completion zone(s). After the fracture in any specific isolated portion of annulus 30a "sands-off", and/or if the pressure in that isolated portion rises to the level of the pressure in the shunts, slurry is then diverted on downstream 20 through the shunts and the process is repeated until the fracturing operation is completed. Accordingly, all of the desired completion zones can be fractured substantially throughout their respective lengths by merely pumping the fracturing slurry until all of the desired zones in the 25 completion interval are fractured and propped.

In some well completions, it may be desirable to leave a particular zone(s) (e.g. zone 13B in FIG. 1) unfractured. In such completions, a portion of the length of each shunt tubes 24 is left blank or unperforated (i.e. have no openings 25 therein) 30 wherein the blank portion of the shunts tubes will lie adjacent zone 13B when fracturing string 15 is in an operable position within the wellbore. Sand bridges 45 will still form at the perforated sections 21, as described above, but now the slurry 45 can only flow into the isolated portions of annulus 30a which 35 lie adjacent zones 13A and 13C and not into zone 13b, thereby leaving zone 13B unfractured.

In many instances, it may be desirable not to take any returns through well annulus 30 during the fracturing operation.

Referring now to FIG. 6, well annulus 30 is closed at the surface and wellbore 11 and workstring 14 is filled with a non-compressible, well completion fluid which is usually present after the drilling of wellbore 11 has been completed.

5 Fracturing slurry 40 is flowed down tubing 17 and out through cross-over 16 into the top of completion interval annulus 30a. Since the flow of liquid from the slurry can not flow through perforated sections 21, it can only flow down the completion interval annulus 30a and into the formation at its "weakest" or

10 most permeable level. As it flows into the formation, it forces at least some of the completion fluid in the annulus 30a ahead of it into the formation.

Once a fracture 50 (FIG. 6) is initiated in the formation (can be anywhere within completion interval 12), both liquid 15 from slurry 40 and completion fluid (arrows 55 in FIG. 6) from within completion interval annulus 30a flow into the fracture due to the pressure of the fracturing slurry being pumped into annulus 30a. As completion fluid 55 is displaced from annulus 30a, liquid 40 from the slurry now begins to enter base pipe 20 through the perforated sections (e.g. 21a, 21b, and 21d) 20 farthest from fracture 50. As liquid 40 enters base pipe 20, it forces completion fluid 55 out through perforated section (e.g. 21c) nearest fracture 50. Continued loss of liquid from slurry 40 through these perforated sections will now cause sand bridges 25 to form at the respective perforated sections to isolate portions of annulus 30a, as described above. Once these sand bridges are formed, slurry 40 can now only flow through the shunt tubes 24c and is delivered to the isolated portions of annulus 30a through the respective shunt tubes to complete the 30 fracturing of completion interval 12.

Once the desired zones have been fractured, the well can then be put on production. Tubing string 17 and cross-over 16 can be retrieved and replaced with a string of production tubing (not shown) which, in turn, can be "stabbed-in" or otherwise 35 connected to fracturing string 15, the latter normally being left in place. Fluids will flow from the production zone(s) within the completion interval 12 and into completion interval annulus 30a. While the sand bridges 45 are substantially

impermeable to the flow of high-viscosity liquids (e.g. fracturing gel having a viscosity of about 100+ centipoises), these bridges are readily permeable to the much-lower viscosity, produced fluids (e.g. oil and gas having viscosities of about ± 1 centipoise). Accordingly, the production fluids can freely flow through the sand bridges 45 which now act as mini gravel-packs, the wire-wrapped screens 31 (if present), openings 22 in perforated sections 21, and into base pipe 20 for production to the surface.

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